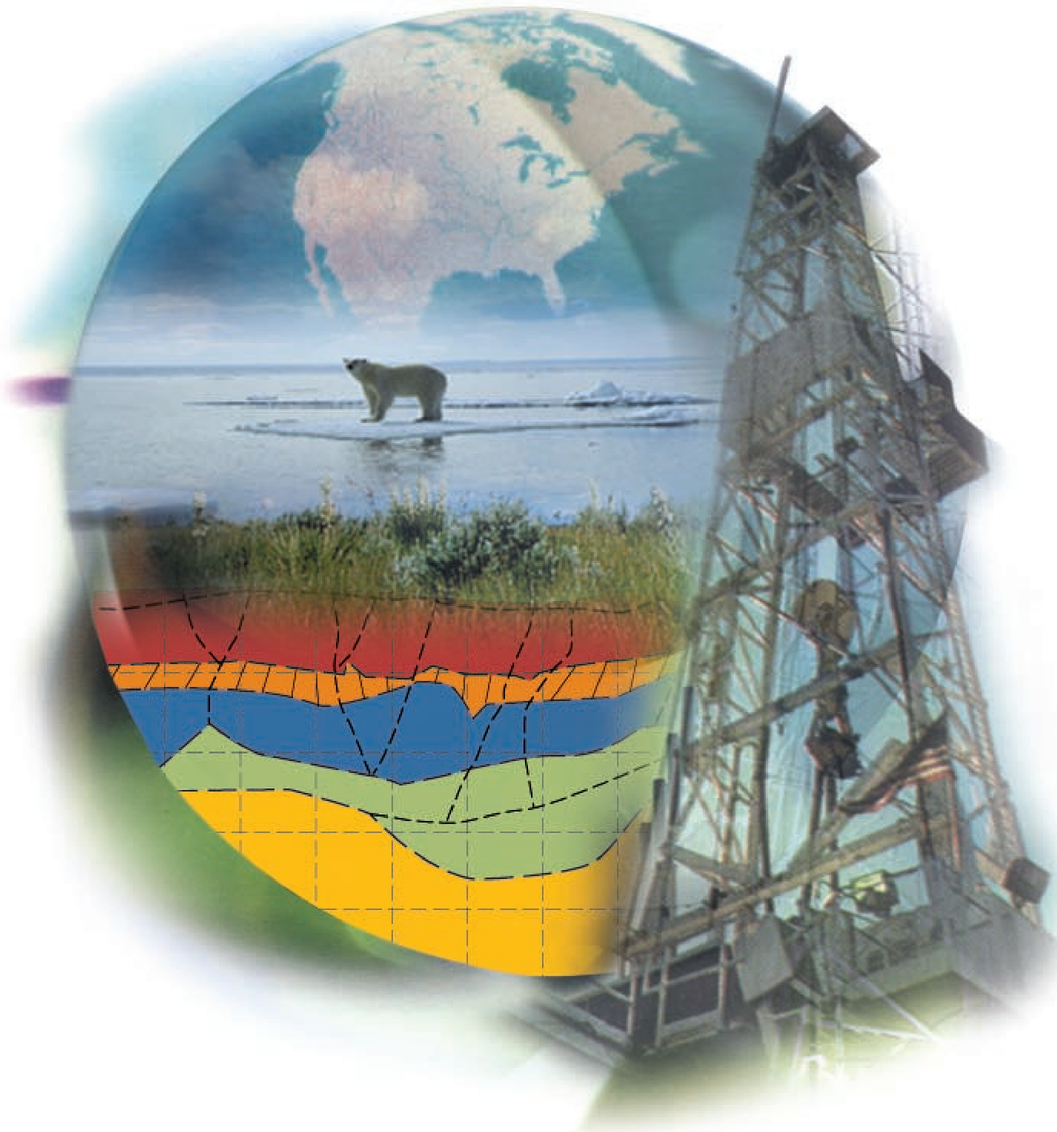
U.S. Department *of* Energy
Office *of* Fossil Energy



Environmental Benefits *of* Advanced Oil *and* Gas Exploration *and* Production Technology

Production

WITH ADVANCED RESERVOIR MANAGEMENT AND OTHER PRODUCTION TECHNOLOGIES, PRODUCERS RECOVER MORE RESOURCES FROM OIL AND GAS OPERATIONS, WHILE MINIMIZING PRODUCED WATER AND OTHER WASTES.

Higher Yields Plus a Cleaner Environment

Since the beginning of the commercial oil industry in 1859, just a handful of U.S. oil fields have topped the 1-billion-barrel mark for production. California's South Belridge field recently joined their ranks, thanks in large part to enhanced oil recovery technology.

The discovery at South Belridge in Kern County was described in 1911 by a San Francisco newspaper as "a small quantity of oil, not sufficient it is believed to be a commercial success." Production levels remained modest throughout the field's early years. A new era began for the field in the 1960s with the advent of steam injection to increase oil recovery. From an average production of 11,370 barrels per day at the end of the 1950s, the field by the end of December 1979 was producing 49,500 barrels per day. With a major development program by Shell, production peaked in 1987 at an average of 174,800 barrels per day. Though decline had set in, the field remained the Nation's fifth most productive oil field in 1994, with production averaging 120,000 barrels per day. By extending the productive life of fields such as South Belridge, enhanced oil recovery technology reduces the need for new exploration and drilling operations—and eliminates their associated environmental impacts.

Source: Oil & Gas Journal, October 16, 1995

Once a field is brought on production, good reservoir management is required to ensure that as much oil and gas as possible is produced as cost-effectively as possible, with minimal waste and environmental impact. Early producers, relying on natural pressure and primitive pumps, recovered only about 10 percent of the oil in a given field. They sometimes vented or flared natural gas produced in association with the oil. In contrast, today's producers use an arsenal of advanced recovery techniques to keep oil and gas resources flowing, enabling them to produce as much as 50 percent or more of the oil resources and 75 percent or more of the natural gas in a typical reservoir.

Progress has been particularly impressive in the last decade. In response to declining crude oil prices and relatively flat natural gas prices in the 1990s, operators throughout North America have initiated major programs to reduce production expenditures, resulting in further technological advances and more streamlined operations. Technology improvements have brought a dramatic decrease in the average cost of producing oil and gas, from a range of $9 to $15 per BOE in the 1980s to today's average of roughly $5 to $9 per BOE.

Producing Energy and Environmental Benefits

Improved production technology has greatly reduced environmental impacts as well as costs. For example, better reservoir management has decreased volumes of produced water, which, at about 15 billion barrels per year, is the largest waste stream generated in U.S. oil and gas exploration and production. On average, the industry produces about 6 barrels of water for every barrel of oil. Since management of produced water is expensive—ranging from about $0.10 to more than $4.00 per barrel—technology to minimize produced water volumes can yield significant cost efficiencies.

Many other advances—such as improved treatment of produced water, better control of hazardous air pollutants, more energy-efficient production operations, and reduction of greenhouse gas emissions from E&P operations—have also made oil and gas production progressively less waste-intensive and more productive.

Production from oil and gas operations generally flows around the clock. A constant stream of performance data allows a producer to reevaluate operations and make appropriate decisions over time.

Surface facilities gather the produced oil, gas, sands, and water into distinct streams. These streams are then processed to remove impurities from oil and gas products, capture gas and water for reinjection if enhanced recovery techniques are in use, and treat and properly use or dispose of any water or solid wastes. Finally, the product is transported to market.

Fundamentals of Production

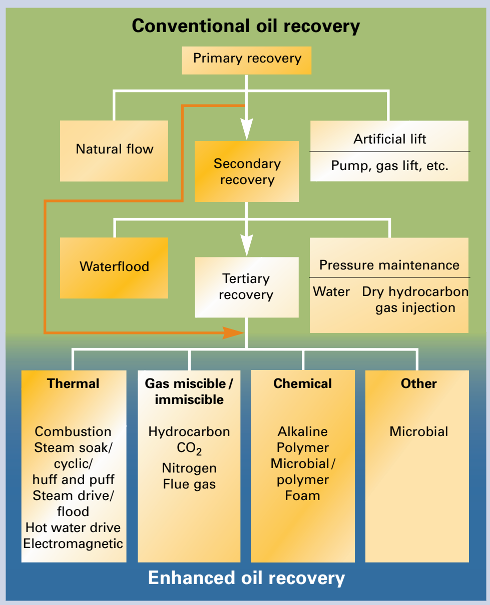
Advances in production technology that contribute significant environmental benefits include:

Improved recovery processes

Rapidly evolving oil recovery technology allows today's operators to extract more residual oil from existing reservoirs, after primary and secondary recovery. Residual oil may be either too viscous to be produced, trapped by interfacial tension, or lying in zones that have not been swept by injected fluids. The application of improved recovery technology has expanded to all producing areas of the country, allowing for production of some of the approximately 350 billion barrels of discovered but unproduced crude oil in the United States. Without improved recovery technologies, such as polymer-augmented waterflooding, the thermal processes of steam or hot water injection, and the injection of gases such as CO_2, flue gas, or nitrogen, these resources would be prematurely abandoned.

Oil and Gas Recovery Processes

Field development can occur in three distinct phases:

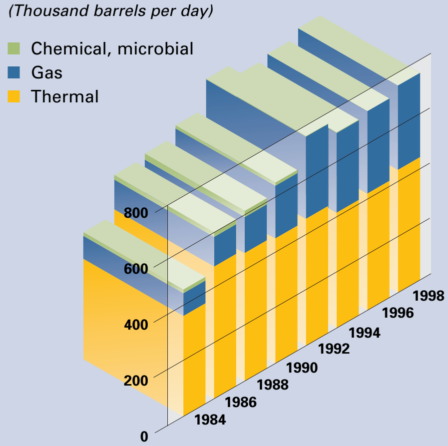


Source: Oil & Gas Journal, April 20, 1998

Enhanced Oil Recovery in the United States

Crude production from enhanced oil recovery

(Thousand barrels per day)



Source: Oil & Gas Journal, April 20, 1998

Primary Recovery

Primary recovery produces oil, gas, and / or water using the natural pressure in the reservoir. Wells can be stimulated through injection of acids or other fluids, which fracture the hydrocarbon-bearing formation to improve the flow of oil and gas from the reservoir to the wellbore. Other techniques, including artificial lift, pumping, and gas lift, help production when the reservoir's natural pressure dissipates.

Secondary Recovery

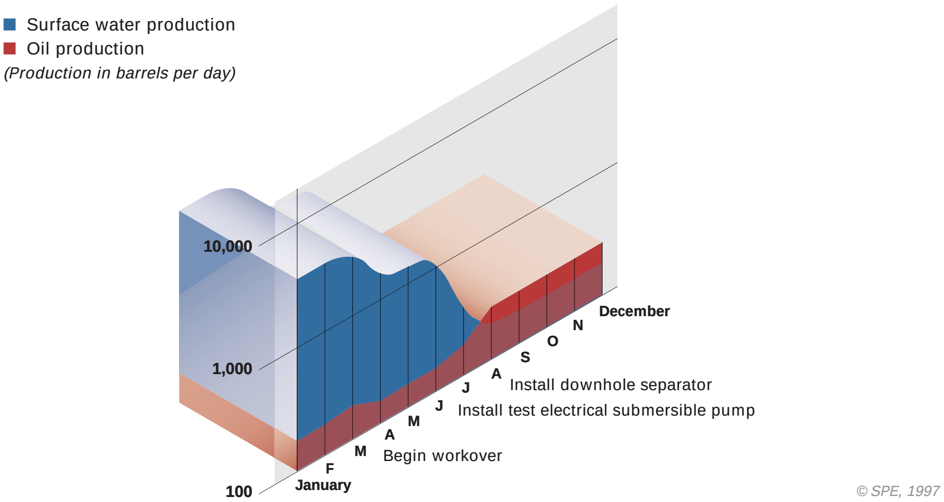
Secondary recovery uses other mechanisms — such as gas reinjection and water flooding — to energize the reservoir and displace fluids not produced in the primary recovery phase.

Enhanced Oil Recovery

Enhanced oil recovery involves the injection of other liquids or gases (such as surfactants, polymers, or carbon dioxide) or sources of heat (such as steam or hot water) to stimulate oil and gas flow and mobilize reservoir fluids that were bypassed in the primary and secondary recovery phases.

METRICS

Actual Example of Reduction in Produced Water Using Downhole Separation



Currently being tested in pilot-scale projects throughout the world, downhole separation may someday deliver significant cost savings and environmental benefits in settings where the technology is applicable. In one recent demonstration (illustrated here), downhole separation decreased surface water production by 95 percent and increased oil production by 50 percent, resulting in a 4-month payback period.

Better reservoir management to reduce water production

Improved understanding of the flow mechanics of reservoirs—resulting from crosswell tomography, crosswell seismology, better logging tools, and other reservoir characterization advances—allows operators to reduce produced water volumes through more selective well placement and selective shutting in of some wells. Developments in completion technology, especially as applied in horizontal wells, are also helping to delay water breakthrough and maintain the ratio of produced oil to produced water as high and as long as possible.

Improved produced water treatment technology

In locations where surface discharge of produced water is still permitted (such as offshore and low-rate stripper wells in Appalachia), a variety of methods are being pursued to treat and reuse the water or discharge it to the surface without environmental impact. Approaches include hydrocyclones, gas flotation, membrane separation, granular activated carbon fluidized-bed reactors, and biotreatment technology.

One particularly promising technology for low-rate well application in some climates and operational settings is the freeze-thaw/evaporation (FTE) process. Using a freeze crystallization process in winter and natural evaporation in summer, produced waters are separated into fresh water, concentrated brine, and solids. The resulting fresh water can be used for horticulture, livestock, and other beneficial uses. The remaining volume of wastes (solids and semisolids) requiring disposal is significantly reduced. This process requires large amounts of land and high volumes of produced water retention and is limited to climates with cold winters and dry summers, such as the Rocky Mountain region, the Northern Great Plains, and virtually all of Canada.

Downhole separation technology

In certain settings, downhole separation represents a potential solution to a significant environmental and cost issue for oil and gas operators: the management and disposal of produced water. In today's operations, water is generally pumped to the surface along with oil, then separated from the oil. Since volumes of produced water can exceed oil production by 10 times or more, companies incur sizeable costs to lift the unwanted water, manage it on the surface, and dispose of it (usually by reinjection into the earth's subsurface). The approach also has the disadvantage of bringing contaminants up through the well piping.

In downhole separation, mechanical or natural methods are used in the wellbore to separate the formation's oil and water. The oil is then brought to the surface, while the water is directly pumped into a subsurface injection zone. In its current state of development, downhole separation is thought to be applicable only to light oil wells with relatively high flow rates and meeting minimum casing diameter and water-to-oil ratio standards.

Field tests are demonstrating that this technology, effectively deployed, has the potential to significantly reduce the produced water brought to the surface in applicable wells, directly reducing fluid lifting and disposal costs, as well as any associated environmental concerns. Downhole separation can also increase oil production in proportion to the decrease in water production.

In many parts of the country, the high cost of produced water management is the main reason for well abandonment. By controlling the increasing costs normally incurred as water volumes increase, downhole separation can potentially increase U.S. oil production and recoverable reserves.

In some cases, downhole separation may also enable increased oil production and recovery of original oil in place through improved or altered water flow distribution in the reservoir. In addition, dynamic control of the oil-water contact can be achieved through dual completion and reinjection.

Depending on how widely downhole separation is applied in the future, as much as 5 billion barrels per year of produced water that otherwise would have been brought to the surface will remain in the ground.

Better leak detection, measurement, and control systems for hazardous air pollutants

Technology advances on several fronts are reducing emissions of hazardous air pollutants in E&P operations. In the last decade, for example, many approaches have been developed to detect, measure, and control air pollutants from a variety of oil and gas field equipment. State-of-the-art leak detection and measurement systems pinpoint fugitive gas leaks, conserving valuable natural gas and identifying potentially life-threatening hazards to workers and the community. Vapor recovery units—economical for large operations with relatively high reservoir pressures and vapor releases—are being employed to reduce emissions of volatile organic compounds from storage tanks by as much as 95 percent. Improved management approaches for glycol dehydrators are also helping to reduce emissions substantially. In addition, new technology for removal and recovery of acid gas (hydrogen sulfide, mercaptans, and carbon dioxide) shows cost savings of 40 percent compared to current technology.

More energy-efficient production operations

Operators increasingly are focusing on ways to reduce energy use in their operations. For example, new stripper well beam pumps have reduced electricity consumption substantially. Improvements in energy efficiency result in corresponding reductions in emissions of air pollutants associated with energy use in production operations.

Better facility-wide waste management planning

The E&P industry, working with States, is aggressively employing technology and practices to reduce or eliminate waste by preventing it at the source. Techniques include better planning, materials management, materials reclamation, and recycling; major changes to E&P processes; improved auditing and maintenance procedures; changes in day-to-day operations to control waste generation; and more targeted employee training.

Increased focus on reducing greenhouse gas emissions

A wide variety of approaches are currently being pursued to reduce emissions of methane, a potent greenhouse gas thought to contribute to global climate change. Methane losses from oil and gas industry operations are considerable, and emission reduction techniques reduce both global emissions of greenhouse gases and the losses of a valuable product. Technology being pursued includes glycol dehydration using a separator-condenser (which can result in emissions recovery of over 95 percent), and replacing high-bleed pneumatic controllers (a particularly large source of methane emissions) with low-bleed pneumatic devices.

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Nature's technology provides water for agricultural and other beneficial uses. In suitable environments and under certain operating conditions, initial field tests indicate the freeze-thaw/evaporation process may reduce the volume of produced water requiring disposal by 80 percent.

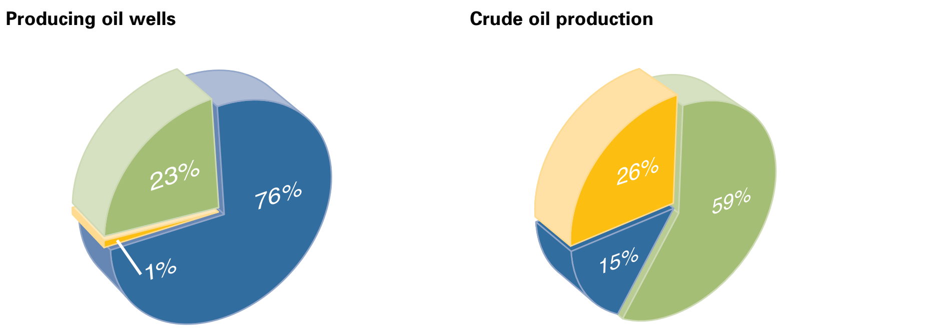
Recent advances in coalbed reservoir engineering and completion practices have also turned coalbed methane—historically considered a safety hazard for mines and vented to the atmosphere—into a reliable energy resource. This resource now accounts for over 5 percent of U.S. gas production and 6 percent of proved gas reserves. Recovery rates are being further enhanced by the injection of carbon dioxide or nitrogen.

Gas-to-liquids technology is still on the cutting edge, but promises to make vast quantities of previously untapped natural gas transportable and marketable. The process chemically alters natural gas to form a stable synthetic liquid that performs more efficiently and with fewer greenhouse emissions than conventional fuels. The North Slope of Alaska alone is estimated to have 25 trillion cubic feet of natural gas that is currently undeveloped because transporting it to markets would be uneconomical. Gas-to-liquids technology may soon enable natural gas, the fuel of choice for environmental performance, to be transported around the world.

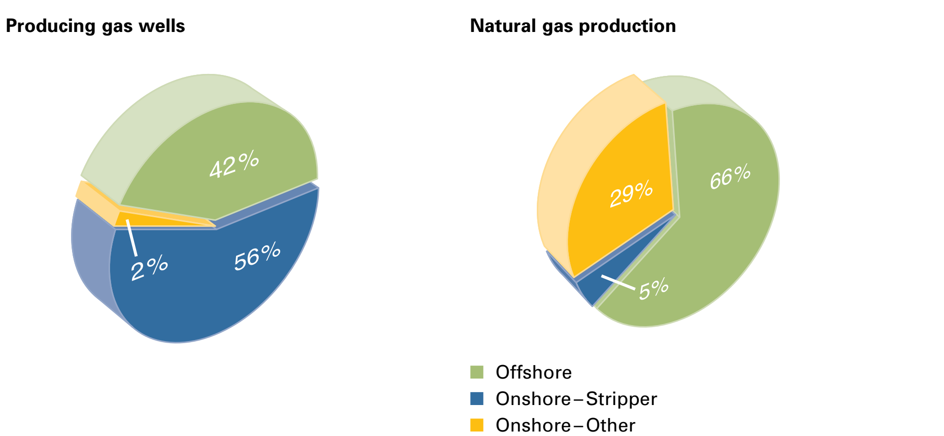
Beyond the Oil Patch

- Developments in reservoir engineering and reservoir simulation technologies and processes have advanced our ability to predict groundwater flows, pollutant fate, and transport in groundwater, and to simulate the diffusion of air pollutants in the atmosphere.
- Adaptations of microbial enhanced oil recovery technology, originally developed for enhancing crude oil recovery, has proven to be quite effective in the remediation of hydrocarbon-contaminated sites.

U.S. Oil Production



U.S. Gas Production



In the 33 oil- and gas-producing States, approximately 574,000 oil wells and 300,000 gas wells currently yield approximately 6.5 million barrels of oil and 54 billion cubic feet of gas per day. Most of these wells—approximately 435,000 oil wells and 170,000 gas wells—are classified as "stripper wells" because they produce less than 10 barrels of oil or 60,000 cubic feet of gas per day.

About 26 percent of U.S. oil production and 29 percent of gas production comes from offshore operations, predominantly in the Gulf of Mexico. Currently, there are over 5,000 producing structures in Federal offshore waters.

Source: American Petroleum Institute; U.S. Department of Energy; Independent Petroleum Association of America; and Interstate Oil and Gas Compact Commission